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Analysis of a Terror Network from a System Dynamics Perspective

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ANALYSIS OF A TERROR NETWORK FROM A SYSTEM DYNAMICS PERSPECTIVE

ABSTRACT

Terrorism is a complex problem and therefore simple solutions focusing just on one aspect are destined to fail. We have to capture terrorism in its entirety and system dynamics offers various tools to support us. We developed a semi-quantitative system dynamics approach aiming to characterize relationships between different variables and their impact on the system as a whole. The authors established a network to model terrorism consisting of 16 variables and performed different analysis to gain a better understanding of the mechanisms behind terrorism. We showed how to determine which variables are suited for intervention and described in detail their effects on the influence of the terrorist organization. The paper gives also an insight how to elicit elements that destabilize and ultimately break down the terror network. Because we clarify our approach using fictitious numbers, the relevance of this work is not so much in specific policy recommendations that it proposes as in the framework for reasoning that it provides.

KEYWORDS

Qualitative System Dynamics, Cross-Impact Matrix, Cross-Time Matrix, Intervention Variables, Path Analysis, Network Stability

INTRODUCTION

The attack on the World Trade Center and the Pentagon on September 11, 2001 brought terrorism back into focus in Western society. Since that date, governments and international organizations have actively combated problems related to international terrorism. In the fight against terrorism, the U.S. took a pioneering approach that was based primarily on military tactics. However, this approach has not succeeded in eradicating terrorism. The 2004 Madrid and 2005 London attacks in Europe displayed a new facet of this barbaric phenomenon: homegrown terrorism. As suggested by the word 'homegrown,' this type of terrorism is carried out by residents or citizens attacking their own country. In the decade since the attack on the twin towers, homegrown terrorism has emerged from a marginal topic to a central issue in contemporary discussions about possible terrorist threats. However, according to Brooks, it is not very meaningful to focus predominantly on homegrown terrorism. In her research, she found that at least in the United States, Muslim homegrown terrorism is not a particularly serious public menace.[1]

The war against terrorism has already lasted for several years, and there is – despite Osama Bin Laden's death – no end in sight. This raises the question of whether alternative anti-terrorist measures could be more promising. In this context, we present an unconventional approach to terrorism. We analyze terrorism from a system dynamics perspective. System dynamics is a method of capturing complex issues in a holistic way, and its focus lies in the crucial elements and their interrelations in a given framework. This approach substantially facilitates the understanding of the behavior of complex systems and enables us to make predictions of the system's evolution and to propose potential measures to change the dynamics of a system. Very few attempts have been done to connect terrorism with system dynamics modeling. Grynkewich tried in his analysis to model the financial subsystem of the 'Salafist Group for Preaching and Combat'. He focused primarily on just one element of

terrorism namely fundraising.[2] On the contrary we built a generic model including several key variables of terrorism.

The aim of this paper is to present a complete new method how to deal with terrorism. We are going to illustrate this method using a model that combines different key aspects of terrorism. Because we clarify our approach using fictitious numbers, the relevance of this work is not so much in specific policy recommendations that it proposes as in the framework for reasoning that it provides.

In particular, we explore the following research questions:

- How can we model a terror network?
- What variables are most influential in this network and thus are suitable for intervention in the system?
- What effect do these intervention variables have on the terrorist organization?
- How can we destabilize a terror network? Which bundles of variables have to be removed to efficiently break down the terror network?

With the aid of simple algorithms, we are capable of modeling the dynamics of a terror network. We argue that an intervention variable must be highly interlinked and should quickly disseminate changes throughout the system. Applied to our model are three variables suited for intervention: *control of overreaction*, *right target of anti-terror measures* and *anti-terror support by moderate forces*. The variable *control of overreaction* means that a country is capable of reacting rationally and adequately following a terrorist attack. There is a danger that governments make highly emotional decisions in such situations and tend to overreact. It is often the case that the retaliation measures are disproportionally severe and hurt not only

the terrorist organization but also civilians. This can aggravate problems related to terrorism and lead to a substantial boost in the recruitment of new terrorists. The variable *right target of*

anti-terror measures has a similar meaning. It is of crucial importance to plan and execute military operations carefully. Retaliatory actions should strike the Achilles' heel of the terrorist organization and weaken it in the long run. The last variable appropriate for intervention is *anti-terror support by moderate forces*. Moderate forces are population groups within a hostile country, area or organization that are opposed to terrorism. These moderate groups are important allies in countries with active terrorist organizations.

We will describe in detail the impacts of *right target of anti-terror measures* and *anti-terror support by moderate forces* on the influence of the terrorist organization. Among the two, right target choice is the most effective in our example. In the final section, we will analyze the robustness of the network by removing single and multiple variables. To completely dismantle our terrorist network, we must approach the problem at three points: *the recruitment of potential manpower*, *the impact of attacks* and *media reports*.

The article is divided in five main sections. First, it provides an overview of the definition, forms and history of terrorism. Second, the article contains a brief introduction to qualitative system dynamics. Third, it presents the terror network and its variables. It concludes with an extensive analysis of the network and resulting recommendations based on our terror model.

DEFINITION, FORMS AND HISTORY OF TERRORISM

Definition

Terrorism is an evolving concept. As the face of terrorism has been changing over the last decades, so has the definition. It adapts to the political language and the political discourses of a particular epoch, which makes it difficult to find a time-consistent, universal definition. Terrorism is a matter of perception and is thus regarded differently by different observers.[3] According to Rossi, terrorism is an instrument of politics based on violence to achieve a specific political goal, regardless of existing peaceful instruments, such as negotiations.[4]

Horchem defines terrorism as the systematic use of murder and destruction to impose a political vision on individuals, groups, communities or governments.[5]

In this context, Waldmann stresses the creation of fear and fright with the aim of undermining the existing social and political order and a subsequent profound transformation of the system.[6] The U.S. government defines terrorism as follows: "*Terrorism means premeditated, politically motivated violence perpetrated against non combatant targets by sub-national groups or clandestine agents, usually intended to influence an audience.*"[7]

According to Kydd and Walter terrorism represents the use of violence against civilians by nonstate actors to achieve political goals. These goals can be: regime change, territorial change, policy change, social control, and status quo maintenance.[8]

Combining the preceding definitions terrorism can be explained by four essential characteristics:[9]

- Terrorism always has a political character. Therefore, violence in conjunction with financial interests or revenge is ruled out.
- Target choice is non-random. We must assume that there is an in-depth preparation and planning phase before a terrorist attack.
- The civil population is struck intentionally. Whereas in a military operation the enemy combatants are attacked, here non-combatants are affected.
- The terrorist organization is composed of non-state actors.

Forms of Contemporary Terrorism

Terrorism can be classified either by its geographical expansion or by its motivation. We use here the latter approach and distinguish between five different forms of contemporary terrorism:

(1) Ethnonationalist/separatist terrorism: Political autonomy is the main feature of this kind of terrorism. Its origin lies in independence movements following the Second World War, which put the colonial powers of different countries under great pressure. The challenged governments reacted impetuously, leading to increased solidarity among large groups of the concerned population and eventually to armed revolution. The key success factor was a clear and easily understandable message shared by a large proportion of the population. A very recent example of this kind of terrorism is Iraq, where different groups competed to maximize their autonomy, to prevent a new order and to weaken the existing government.[10]

(2) Social-revolutionary terrorism: Inspired by successful activities of nationalistic terrorists, so-called social-revolutionary terrorism developed in Western Europe in the 1960s and 1970s. The background was mostly communist or socialist, and those engaging in this type of terrorism have attracted worldwide attention through spectacular actions.[11] However, the success rate was minimal, and the terrorists were unable to gain any political concessions from their democratic opponents, nor could they provoke overreactions. With the fall of the Iron Curtain, social revolutionary groups such as the RAF (Rote Armee Fraktion) lost their ideological basis and are no longer active.

(3) Vigilante terrorism: This type represents the counterpoint to social-revolutionary terrorism. There is no aim to weaken the existing state or government. Vigilante terrorists try to strengthen existing law and order by targeting groups, especially minorities, that are seen as the cause of social and welfare problems. The danger of this form of terrorism is the erosion of the legitimacy and stability of a government. Under the cloak of fighting terrorism, vigilante groups may act as free riders and perpetrate violence against minorities.

(4) Single-issue terrorism: This new form of terrorism was developed at the end of the 20th century. This is a very specialized form of terrorism, one that involves, for instance, radical anti-abortionists or eco-terrorists.

(5) Religious terrorism: The phenomenon of religiously motivated terrorism is widely discussed, and many scholars consider this form of terrorism to be currently the most important and most dangerous. With respect to religiously motivated terrorism, one must distinguish whether it is linked to political objectives or to a fanatic religious understanding, where the terrorists define themselves as an instrument of a divine will. It is obvious that the potential for violence is much higher with regard to the second form.[12] In reality, often both forms are combined. Recent developments clearly indicate that violence associated with religious terrorism has been increasing since the beginning of the 1990s. Even though the number of terrorist acts has declined, the number of victims has risen sharply.[13] For example, the activities of Al-Quaida in the period from 1998 to 2004 were responsible for 0.1 % of all terrorist attacks but 19 % of all victims during that period, due to 9/11 and subsequent attacks in Bali, Madrid and London.

We will focus in this paper on religiously motivated terrorism because it is currently the most important form of terrorism.

Historical Review

Terrorism is not a modern phenomenon. The Zealots-Sicarri, Jewish terrorists fighting against Roman governance in Judea, killed their victims with poniards in the heart of Jerusalem in the first century B.C.E.[14] The term ‘terrorism’ was officially used the first time in history during the French Revolution. At that time, however, in contrast to today, the term ‘terrorism’ was positively associated with power and the newly established French government.[15] The ‘régime de la terreur’ over the years 1793-94 was used as an instrument for the enforcement of law and order in a time of disturbances and riots. In intimidating political opponents, dissidents and subversive elements, the new government wanted to send a clear message that resistance to the Revolution was futile and suicidal. According to Rapoport's fundamental studies on the phenomenon of ‘holy terror,’ religion was the only justification for terrorism until the 19th

century.[16] However, with the end of divine right monarchies in Europe and at the beginning of the 19th century, the motivation for terrorism changed from religiously motivated terrorism to secularly motivated terrorism. It was no longer religion that stood behind terroristic activities but a new understanding of the roles of the citizen and the state as well as a new interpretation of nationalism and self-determination. The Marxist ideologies, anarchism and nihilism legitimized terroristic activities to improve the state and the welfare of the public.[17]

In 1968, members of the Popular Front for the Liberation of Palestine (PFLP) hijacked an airplane of the Israeli airline El-Al in a highly symbolic terroristic act. According to Hoffman, the year 1968 can be described as the year marking the beginning of modern international terrorism.[18] In 1968, only 5 out of 52 identified terrorist groups could be regarded as religiously motivated (none of them were internationally active); the rest were fighting for secular reasons.[19]

The first 'modern', internationally active and religiously motivated terror groups were detected following the 1980 Iranian revolution. In subsequent years, the number of religiously motivated terror groups increased dramatically. Initially, this movement was closely linked to Islam, but by the next decade, terrorist activities were being carried out in the name of all major world religions. No religion was completely immune to the dangerous mixture of faith, fanaticism and violence.[20] In 1994, about one-third (16 out of 49 groups) could be classified as 'religiously motivated', whereas by 2004, this proportion had risen to 42 %.[21] Indeed, the enormous importance of religion as the main impetus of international terrorism was evident before 9/11. All of the most serious terrorist attacks of the past decade can be attributed to religiously motivated terrorism.[22]

QUALITATIVE SYSTEM DYNAMICS

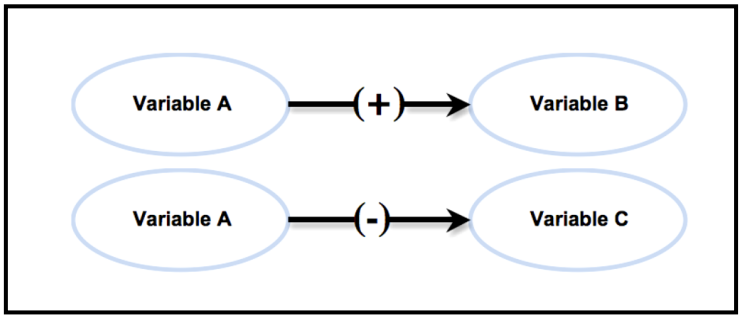
A system dynamics approach differs substantially from traditional analyses. Traditional analyses divide the subject of interest continuously into further specialized disciplines and focus on a small number of linear causal relationships between phenomena, explaining them in terms of their smallest identifiable parts. However, this approach often leads to incorrect results and creates inappropriate incentives. In contrast to these traditional analyses, system dynamics concentrates on how a subject of interest interacts with other variables. Rather than breaking a system down into smaller components, system dynamics expands the view of a user, taking into account increasingly greater numbers of interactions. Maani and Cavana[23] define system dynamics as "the ability to see things as a whole. It combines the art of seeing interconnections and the science of explaining complexity." System dynamics implies that the variables of a system have to be considered in a dynamic way and requires thinking in terms of processes instead of steady states. System dynamics focuses, on the one hand, on the interactions between the different variables in a certain system *and*, on the other hand, on the interactions between the different variables and the system as a whole. Internal and external influences affect the relations between the variables of a system and often do not occur deterministically.[24] Feedback processes are important in this context. They can be either direct or indirect and can dramatically influence the behavior of a system.

To use qualitative system dynamics, we must establish a network. To do so, the most important stakeholders and their objectives as well as their relationships have to be modeled.

In general, the relationship between two variables can be either positive or negative. A positive relationship means that an increase in variable A leads to an increase in variable B, and a negative one implies that an increase in variable A leads to a decrease in variable C (see Figure 1). To perform an analysis, we must specify the type of relationship between two

variables, the strength of their interaction, and the time required for one variable to influence another.

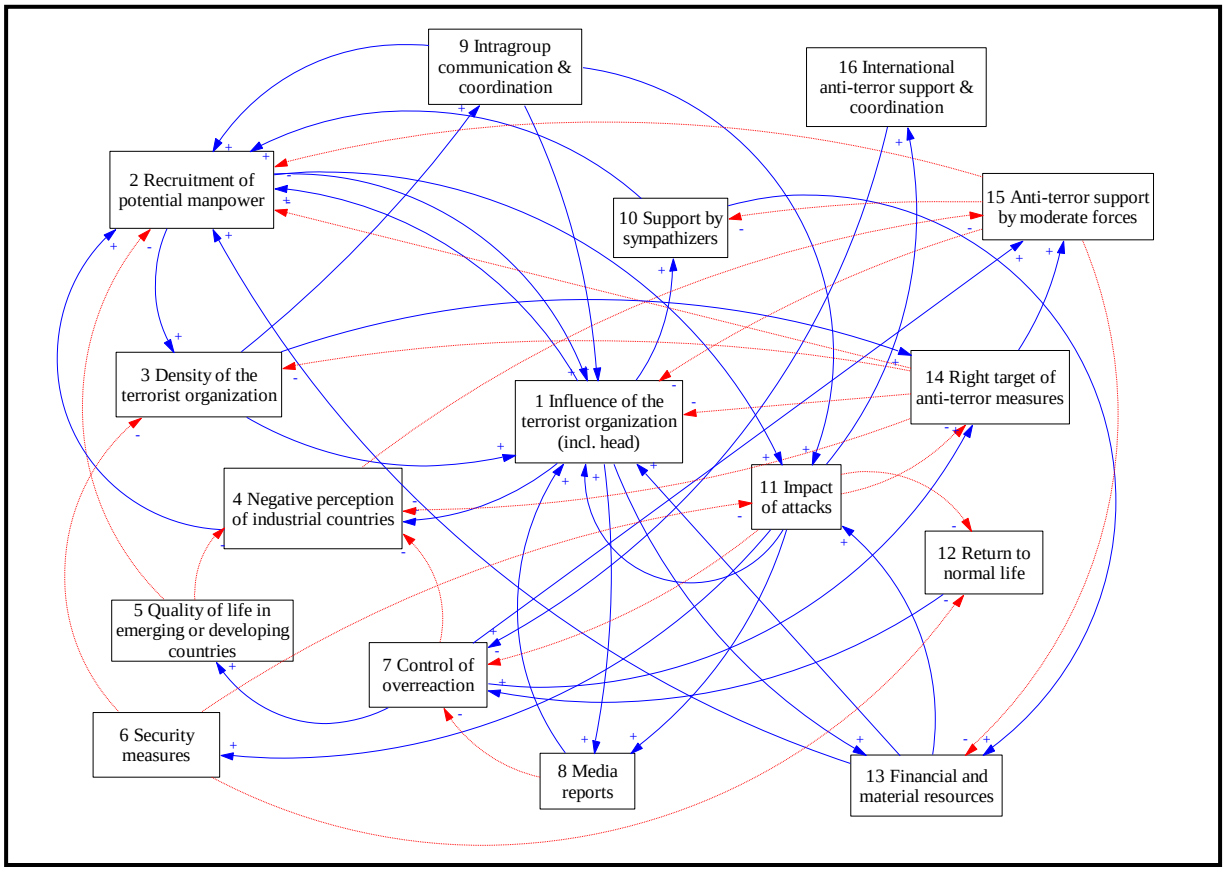
Figure 1. Possible relations of two variables in a network



THE TERROR NETWORK

The terror network presented in Figure 2 and analyzed in this paper is based on the network established and published by Frederic Vester after 9/11 and adapted to international developments in this area.[25] Vester, a pioneer in qualitative system dynamics, presented his terror network, called 'terror prevention,' some months after 9/11 and was able to visualize the impact of the countermeasures taken by the US government. In his preliminary conclusions – based on the network's cybernetics – he emphasized that the pursuit of the head of the terror network has only a very small impact on the network and does not destabilize it.

Figure 2. The terror network



Starting with Vester's network we shifted the focus from a US-based network to a more international one because, since 9/11, there have been terrorist attacks in other countries such as 2002 in Bali[26] and 2005 in London.[27] The attacks in Bali and London claimed smaller numbers of victims than the 9/11 attacks but had disastrous consequences nonetheless. Al-Quaida played an important role in both attacks. The London attack was carried out by a group with the same ideology as Al-Quaida,[28] and the Indonesian terror branch 'Jeemah Islamiah' was responsible for the Bali attack.[29] The network in Figure 2 presents the activities of a large, internationally active terrorist organization such as Al-Quaida for example. According to Andreas Wenger, professor of International Security Policy at ETH Zurich, this kind of organization has to be fought in the near future. Al-Quaida carried out attacks in Western (and, increasingly, Asian) countries not only to weaken these countries' economies and governments but also to provoke military overreactions. These overreactions are likely to

strengthen the conservative and anti-Western forces in the Al-Quaida's home countries and weaken liberal forces more receptive to Western values.[30]

The revised terror network is composed of 16 influencing variables. The interconnections between the variables can be either positive (solid lines) or negative (dotted lines). The network shows the impacts of attacks as well as the impacts of countermeasures taken by governments. The network contains all stakeholders involved in terror activities, which are identified as aggressors, victims or governments.

THE VARIABLES IN THE TERROR NETWORK

(1) *Influence of the organization, inclusive of its leadership*: This variable involves the management and leadership of a terror organization. Terror organizations are often managed in a very strict hierarchy, and power is not concentrated in one person but in several people. This prevents the destruction of entire organization if the leader is killed or captured. However, the charisma of a leader is not to be underestimated. The leader often serves as a figurehead and represents the values and culture of the terrorist network.[31]

(2) *Recruitment of potential manpower*: This element involves people's willingness to sacrifice their lives for a certain ideology. Their hatred and conviction have reached such an extent that they are ready to sacrifice themselves for this cause. The motivation to engage in terrorist actions can originate from multiple sources. A strong wish for a change with respect to politics or religion is generally the initial driver. A blind religious zeal aiming at destroying existing structures can lead to terror attacks, but a wish to gain public attention for certain objectives or the spread of symbolic messages can also be reasons to carry out terrorist attacks.

(3) *Density of the terrorist organization*: This parameter can be understood as the number of terrorists per area (region/country). A high density indicates a high number of terrorists

collaborating in a specific region and thus implies the possibility of substantial knowledge transfer. In such an environment, a terrorist organization is capable of planning and executing sophisticated attacks. However, the risk of being caught increases dramatically. Since 9/11, terror networks have changed their structure and have become more decentralized. Today, they have few central leaders but have increased the number of autonomous militant terror cells.[32] Under this organizational form, less information can be exchanged, but the danger of being discovered is considerably lower.

(4) *Negative perception of industrial countries*: This variable involves denial and bitterness with respect to Western standards and ideologies and can be attributed to different causes. One of these causes may be globalization and the opinion that only Western countries have benefited from it. Another cause could be Western values and culture, which do not fit with their traditional values.[33] Often Western countries are regarded as arrogant and as not respecting other cultures and traditions. If the influence of negative perceptions increases, then the power of the terrorist organization will increase, and it will be easier to recruit new terrorists for attacks.

(5) *Quality of life in emerging or developing countries*: This element addresses the quality of life in non-industrial countries. Normally, the standard of living is higher in industrial countries because citizens have political rights and can intervene in political or social problems. In contrast, in emerging or developing countries people have almost no rights and thus feel helpless and exposed to the power of the regime. Depending on the government, religious tolerance can also vary considerably, which may lead to the persecution of religious minorities.

(6) *Security measures*: The protection of the civil population is a prominent goal of every government. However, complete protection is not possible, as the control mechanisms

required to accomplish this would ruin a democracy and undermine its population's civil liberties.

(7) *Control of overreaction*: Overreaction after a terrorist attack must be avoided. There is some danger that, immediately after an attack, highly emotional decisions are made, and rational thinking is undermined. Resulting countermeasures that punish not only the terrorists but entire populations are counterproductive and tend to generate more support for the terrorists. The danger of overreaction increases not only following an attack but also in advance of a potential attack. National security advisers and intelligence services often receive warnings about terrorist activities. Their overreaction could lead to permanent mobilization on the part of the terrorists.[34]

(8) *Media reports*: Reports in the press are very important because attacks without any echo in the media are regarded as a failure. Media reports are essential for the terrorist organization to spread their ideologies, objectives and political ambitions.

(9) *Intragroup communication and coordination*: This variable is related to the density of the terrorist organization. Increased collaboration and exchange of knowledge among terrorists before an attack has a greater effect. Communication and coordination are essential ingredients for a successful operation.

(10) *Support by sympathizers*: Sympathizers or followers are important for the purchasing of resources (material, infrastructure, people and money). Sympathizers can involve regimes that share the same cultural background or the same values as the terrorists or can involve single persons or foundations giving money to terrorists.[35]

(11) *Impact of attacks*: This element incorporates several aspects: the symbolism of an attack, the number of people injured or killed and economic damages. An attack with greater symbolic value is more beneficial for a terrorist organization. For example, 9/11 was very

successful as a symbolic event. Within a few hours, Al-Quaida was known worldwide for having successfully attacked the powerful US and, with it, Western civilization as a whole.

Whereas the number of injured or dead people can be estimated, the amount psychological damage, such as trauma or depression, is difficult to measure. Further damages, such as water and environmental pollution, as well as the inhalation or consumption of resultant toxic substances intoxication, can form part of this variable.

The terrorist organization wants to weaken the economy of its enemies. An attack that inflicts more damage is more successful. Economic damage includes the destruction of houses and other infrastructure as well as decreasing stock prices and trading volumes in international capital markets.[36,37]

The economic effect of 9/11 was estimated by the OECD to be 27 billion dollars.[38]

(12) *Return to normal life*: A return to normal daily life should be the central objective of all anti-terror measures. Although a life with no terrorism may be a utopian ideal, the goal of anti-terror policy ought to be to enable the population to live as normally as possible and to employ minimal security restrictions. This entails a friendly coexistence of all different states and an appreciation of different cultural values.[39]

(13) *Financial and material resources*: Continuous financial inflows are of prime importance to terrorist organizations. Their financial resources include all the money coming from different activities of the sympathizers, such as kidnapping, arms and drug trade or the abuse of donations or Hawala transfers. [40] Material resources include passports, arms, communication facilities, transportation options and rented housing, which serves as shelters or local headquarters for the terrorists. Due to the lack of concrete data, there exist only estimates of these resources.[41] Experts have estimated Al-Quaida's budget for the period 2001-2004 to have been 20-50 million dollars.[42] The budget for all Arabic/extremist terror

organizations in 2001-2004 is estimated to have been 300 million dollars. If it is true that the direct costs for 9/11 were approximately 200,000 dollars,[43] the terrorist organizations have enough money to plan and execute other activities.

(14) *Right target of anti-terror measures*: Choosing the right target of anti-terror measures and avoiding overreaction are very important. History has shown that blind countermeasures can have negative effects. The destruction of civil infrastructure, such as homes, hospitals or schools, can be very counterproductive and increase a local population's support of a terrorist organization. Terrorists must be identified and specifically persecuted.

(15) *Anti-terror support by moderate forces*: Moderate forces are population groups in a hostile country, area or organization that are against terrorism. They can be composed of politicians who would like to introduce democratic reforms into politics or military forces that actively combat terrorism.[44] In general, moderate forces are all parts of the population that address social and political grievances with peaceful approaches, such as demonstrations. These moderate population groups are important allies in countries fostering terrorism. Therefore, communication and dialogue with these forces must be pursued and facilitated.

(16) *International anti-terror support and coordination*: This variable involves international anti-terror support and all anti-terror countermeasures taken by allied governments, institutions and organizations. Coordination and the common planning of activities are important in this regard. This includes military support as well as data and information exchange, embargos and economic sanctions. The success of these actions depends on how well the different actors are collaborating and following a common project or program. Because national states have different objectives, it is not always easy to define a common project or program. Collaboration can be very complicated if new, non-traditional alliances must be established and states sharing a cultural background with the terrorists have to be involved.

ANALYSIS OF THE NETWORK

In a first step we built a network to illustrate how the different variables are linked together. Now we are interested to know in which *direction* one variable influences another and if this happens immediately or with *delay*. In order to quantify impact and time delay we use two matrices: Cross-Impact Matrix (CIM) and Cross-Time Matrix (CTM). It is very important to notice that the data filled in the matrices are solely for *didactic* purposes and are not validated by experts. The goal of this section is to present a new method how security experts could approach terrorism.

Impact of the different Variables

To describe the influence of each variable, we use a Cross-Impact Matrix (CIM). In contrast to other authors as Gomez and Probst or Vester, we value only direct relationships and ask decision makers to complete the CIM accordingly.[45] To indicate the strength of the variables' relationships in the terror network, the following code is used:

Table 1. Codes used to describe the impact

-1	⇔	**inversely proportional**
Variable B reacts inversely proportional in reference to a shift in variable A		
0 (empty)	⇔	**no influence**
There is no direct link between variables A and B		
+1	⇔	**proportional**
Variable B reacts proportionally with regard to a shift in variable A		

Consequently, we evaluate each link between two variables as either +1 or -1. We could also expand the range of code with disproportionately low (2/3) and high (3/2) impact values but for didactic reasons we preferred to work in this paper with proportional and inversely proportional effects.

Table 2. Cross-Impact Matrix

	Variable name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	AS
1	Influence of the terrorist organization (incl. head)		1		1				1		1			1				5
2	Recruitment of potential manpower	1		1								1						3
3	Density of the terrorist organization	1								1					1			3
4	Negative perception of industrial countries		1													-1		2
5	Quality of life in other cultures		-1		-1													2
6	Security measures			-1								-1	-1					3
7	Control of overreaction				-1	1									1	1		4
8	Media reports	1						-1										2
9	Intragroup communication & coordination	1	1									1						3
10	Support by sympathizers		1											1				2
11	Impact of attacks	1					1	-1	1				-1		-1		1	7
12	Return to normal life							1										1
13	Financial and material resources	1	1									1						3
14	Right target of anti-terror measures	-1	-1	-1	-1											1		5
15	Anti-terror support by moderate forces	-1	-1								-1			-1				4
16	International anti-terror coordination							1										1
	PS	8	8	3	4	1	1	4	2	1	2	4	2	3	3	3	1	
	Degree of cross-linking (AS + PS)	13	11	6	6	3	4	8	4	4	4	11	3	6	8	7	2	

The *active sum* (AS) is the sum of all of the direct influences (outgoing flows) that can be attributed to a certain variable. It is the sum of the values in the row of a single variable and indicates how strongly this variable affects or dominates the system. A high active sum (AS) indicates great influence in the system. The *passive sum* (PS) is the sum of all of the incoming flows and indicates how strongly a variable is affected or dominated by the system. To calculate the incoming and outgoing flows, only the absolute values can be taken into account.

The *degree of cross-linking* depicts how strongly the different influencing factors are interconnected. A higher number indicates that a variable is more essential for the survival of the system. Hence, the removal of a highly interlinked element from the system may lead to a

partial or complete collapse of the system.

Table 2 presents the results of the Cross-Impact Analysis. In our terror network, we are mostly interested in the dynamic evolution of the *influence of the terrorist organization*. This element is of crucial importance for the entire terror system, as is reflected in its having the highest degree of cross-linking of all variables. In addition, this variable has more ingoing than outgoing links, meaning that this influencing factor is very sensitive to changes in the terror network. The variables *recruitment of potential manpower* and *impact of attacks* are also of particular significance. Both have a high degree of cross-linking but differ in the ratio of the active sum to the passive sum. The element *impact of attacks* has the highest active sum in the entire network. Therefore, the entire system is sensitive to change in this specific element. This finding of the Cross-Impact Matrix is not surprising. To maintain a certain level of influence, the terrorist organization must rely on the continuous hiring of new manpower and must execute terror attacks that feature high symbolic value. Therefore, it is logical that these variables occupy a central position in the network.

Time Delay

In qualitative system dynamics, *time* plays a major role. We are interested to know how a system or network develops over time. If we adjust one variable, the effect will not spread immediately through the system. Therefore, there are delays that we must include in our model. To accommodate time in this setup, a Cross-Time Matrix is constructed. The procedure is analogous to the construction of the Cross-Impact Matrix. Again, for the sake of complexity and clarity, only direct links are taken into account.

The matrix is compiled with the following data (see Table 3):

Table 3. Codes used to indicate time delay

0 (empty)	⇔	**no influence**
There is no direct link between variable A and B; consequently, no delays can occur		
1	⇔	**short-term (< 1 year)**
If variable B reacts with a short time delay to a change in variable A		
2	⇔	**middle-term (1-3 years)**
If variable B reacts with a moderate time delay to a change in variable A		
4	⇔	**long-term (> 3 years)**
If variable B reacts with a long time delay to a change in variable A		

To avoid bias, the time categories must be associated with real numbers and coded proportionally. It should be noted that, depending on the system, the time categories can refer to different time frames.

Table 4. Cross-Time Matrix

	Variable name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	PD
1	Influence of the terrorist organization		2		4				1		1			2				2.0
2	Recruitment of potential manpower	2		1								2						1.7
3	Density of the terrorist organization	2								1					2			1.7
4	Negative perception of industrial countries		4													1		2.5
5	Quality of life in other cultures		4		4													4.0
6	Security measures			1								1	1					1.0
7	Control of overreaction				1	1									1	2		1.3
8	Media reports	1						1										1.0
9	Intragroup communication & coordination	2	2									2						2.0
10	Support by sympathizers		1											2				1.5
11	Impact of attacks	1					1	1	1				1		1		1	1.0
12	Return to normal life							1										1.0
13	Financial and material resources	2	2									2						2.0
14	Right target of anti-terror measures	1	1	1	1											1		1.0
15	Anti-terror support by moderate forces	4	2								4			4				3.5
16	International anti-terror coordination							2										2.0
	RD	1.9	2.3	1.0	2.5	1.0	1.0	1.3	1.0	1.0	2.5	1.8	1.0	2.7	1.3	1.3	1.0	

Produced delay (PD) and *received delay* (RD) are mean values of every row (PD) and column (RD).

Figure 3. Produced and received delay

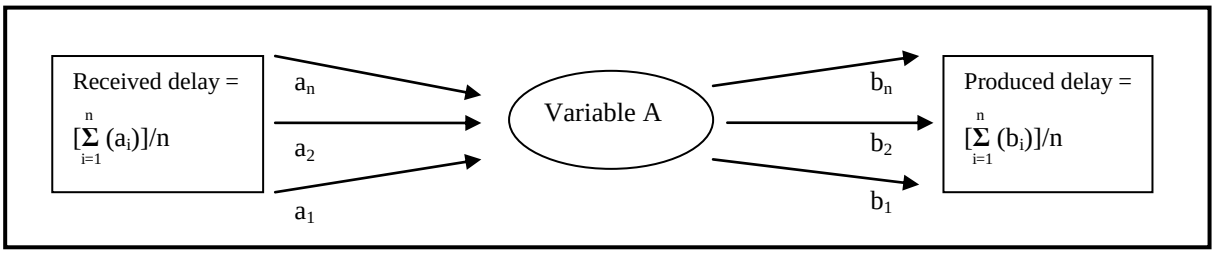


Figure 3 is a schematic representation of produced and received delay with respect to a variable A. Produced delay is the average time an impulse needs to reach a subsequent node from variable A. This is a measure of how much delay a variable causes in the entire system.

On the contrary, received delay indicates the average time required for an impulse to arrive at variable A from a preceding node. Therefore, received delay is a measure of the time required for variable A to react to changes in the system.

Intervention Variables

From a system dynamics perspective, it is of special interest which variables are suited for *intervention*. These elements must have a great impact on the entire system and act with no or little time delay. To identify such influencing factors, it is necessary to combine the Cross-Impact and Cross-Time Matrix. More precisely, a coordinate plane is created with the produced delay on the abscissa and the active sum on the ordinate.

Figure 4. Best intervention variables

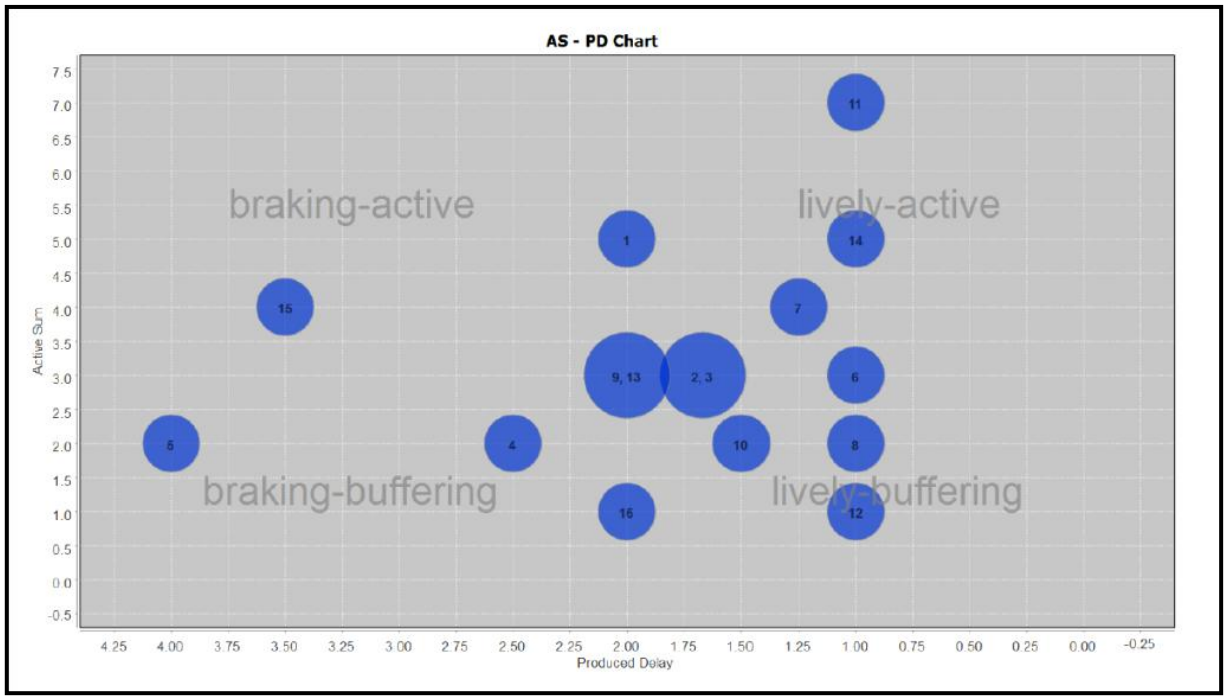


Figure 4 shows a portfolio in which impact and time are reflected. The coordinate plane can be divided into four quadrants each representing a specific cluster of variables with respect to impact and delay. The terms *braking* and *lively* refer to the time dimension, and *active* and *buffering* refer to the impact dimension.

An ideal intervention variable ought to have a dominant position in the network and thus a high number of outgoing links (high active sum). In addition, an appropriate element for intervention ought to quickly spread stimuli throughout the network (low produced delay). Therefore, the best intervention variables are found in the upper-right quadrant, which is labeled *lively active*.

However, an intervention variable must be controllable by policy makers. Consequently, this excludes variables 1 (*influence of the terrorist organization*) and 11 (*impact of attacks*) from being an ideal intervention element because individuals outside the terror network simply cannot influence these parameters. Variable 14 (*right target of anti-terror measures*) satisfies the criteria of a perfect steering element and is controllable. This means for a government that actively fights terrorism, choosing the right target to weaken the terrorist organization is of crucial importance. This is a reasonable and clearly anticipated result. Other variables suited for intervention are more difficult to determine from Figure 4. If we place greater weight on the active sum than on produced delay, two additional variables will come into consideration: variables 7 (*control of overreaction*) and 15 (*anti-terror support by moderate forces*). The *control of overreaction* is an essential element in the terror network. Terrorists aim to provoke disproportionate and rash retaliations following an assault. This significantly facilitates the recruitment of new terrorists and irreversibly deteriorates the reputation of the retaliating country. Therefore, the use of a control mechanism with respect to premature and blind retaliation is very important for addressing terrorism. Variable 15 (*anti-terror support by moderate forces*) is another plausible intervention option for decision makers. This element has considerable impact on the entire system but acts slowly.

Path Analysis

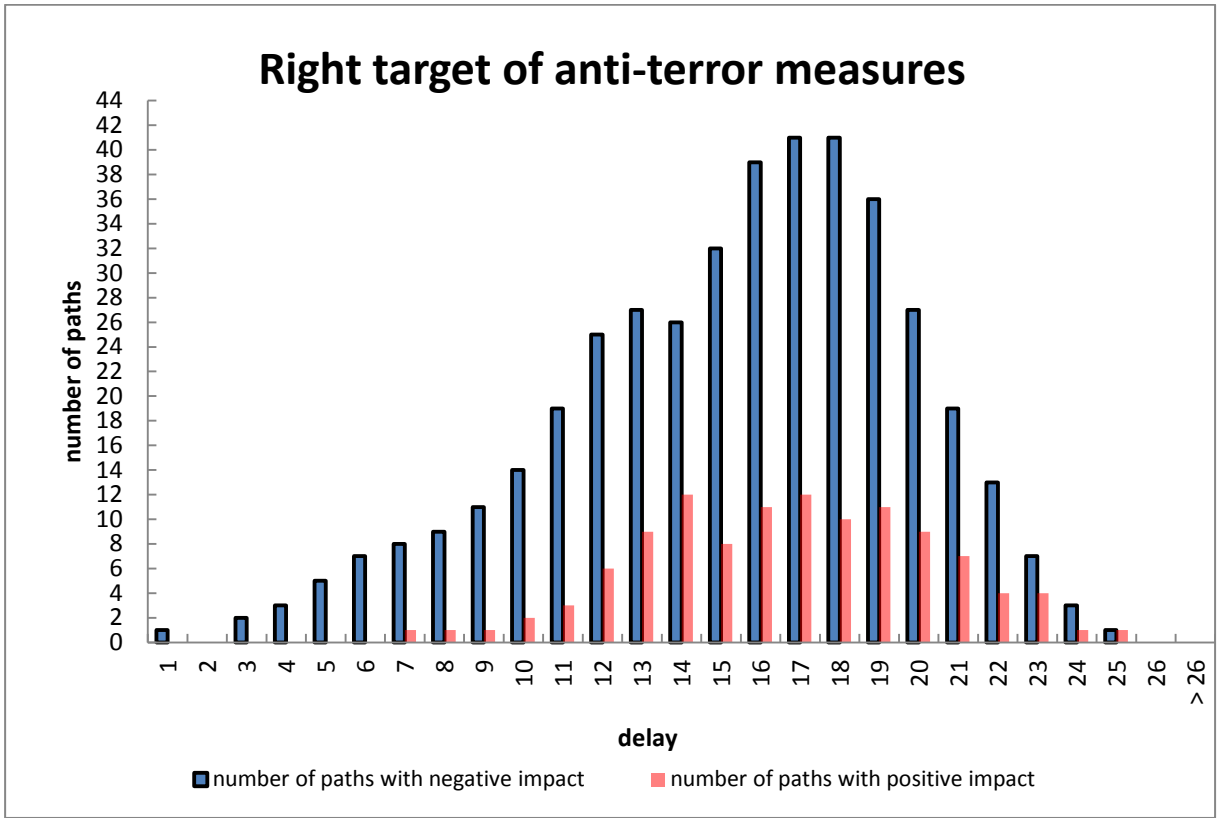
In the next step, we analyze the consequences of intensifying (positively stimulating) our detected intervention variables. We are interested in measuring their effects on the most important variable: the *influence of the terrorist organization* (variable 1). To do so, various *path analyses* are executed. A *path* is a sequence of links connecting a starting variable to a target variable. In complex networks such as our terror network there are potentially hundreds of paths between two nodes. The following questions are of particular interest in this context:

- How many different paths in the terror network exist from the intervention variable to the target variable (*influence of the terrorist organization*)?
- When do these paths arrive at the target variable (time delay)?
- What is the effect of these paths?

To calculate the different paths and their corresponding effect and delay, we applied a pathfinder algorithm. The algorithm takes the initial variable and searches for *all* possible paths toward a target node.[46] It is important to notice that each path is unique and that a vertex can be crossed only once per path.

Figure 5 displays the results of the first path analysis between the intervention variables *right target of anti-terror measures* (variable 14) and *influence of the terrorist organization* (variable 1).

Figure 5. Frequency distributions of all paths between variables 14 and 1



In total there are 529 possible paths that conjoin these two variables. The vast majority (416) have a negative impact on the influence of a terrorist organization. In Figure 5, these paths are represented by dark, framed bars. However, there are 113 paths that boost the influence of a terror network (bright bars). First, the results confirm the obvious: the careful choice of target by a retaliating country has a significant negative impact on the influence of a terrorist structure.

As a measure of effectiveness, we propose to examine primarily the ratio between the total number of negative and positive paths:

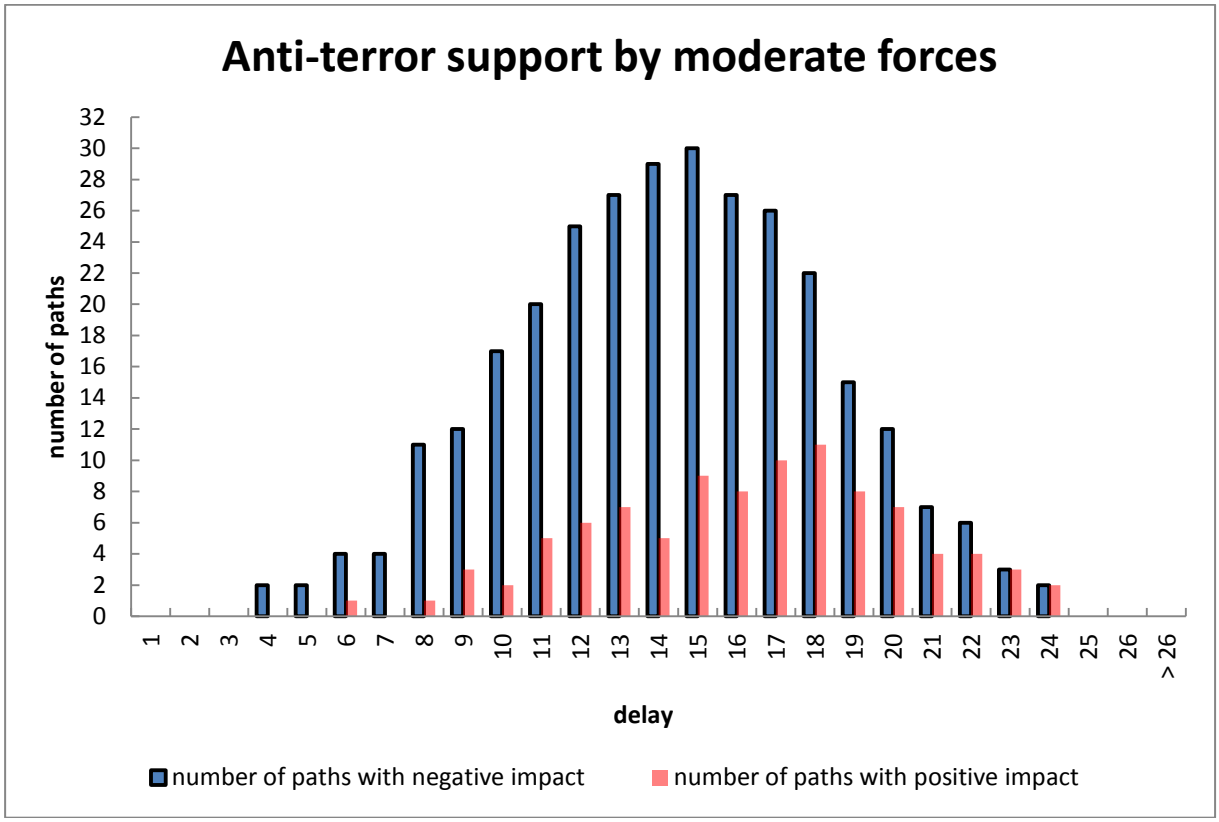
Total number of negative paths / total number of positive paths = 416 / 113 = 3.68

This parameter becomes important if different intervention variables are compared with respect to the influence of the terrorist organization.

Now, we more closely examine the two distributions (dark and bright distributions) depicted in Figure 5. It is important to note that the values on the abscissa have per se no explanatory power but that in relation to other distributions we can make a statement using these values. The frequency distribution resulting from the negative paths is *negatively skewed.* In comparison with a Gaussian distribution, the left tail is longer, and the mass center is located on the right side. The extended left tail implies that choosing the right target of anti-terror measures will have a substantial and immediate negative effect on the influence of the terrorist organization. However, due to the asymmetry of this distribution, the median lies slightly to the right. Consequently, it takes a long time for the full effect to be measurable in the target variable. The frequency distribution resulting from the positive paths will never be detectable and is completely overlapped by the other distribution.

To offer a possibility of comparison, we show also the results of a second path analysis between the intervention variable, *anti-terror support by moderate forces* (variable 15), and *influence of the terrorist organization* (variable 1).

Figure 6. Frequency distributions of all paths between variables 15 and 1



Between these two variables, we have 399 paths in total. The effectiveness ratio in this case is 3.16. Therefore, *anti-terror support by moderate forces* continues to have a considerable negative impact on the influence of the terror network but is certainly less striking than the right target selection.

The dark frequency distribution is approximately bell-shaped, meaning that the tail regions are thin and that the mass is concentrated around the mean. Therefore, no or little negative effect is detectable within a short period of time. In contrast to right target choice (variable 14), it takes less time for *anti-terror support by moderate forces* to have its full effect on the target variable. What is remarkable is that the medians of the two distributions differ significantly. In Figure 6, we see that when the dark distribution is peaking, the other is still rising. Consequently, we measure only little or no negative impact on the *influence of the*

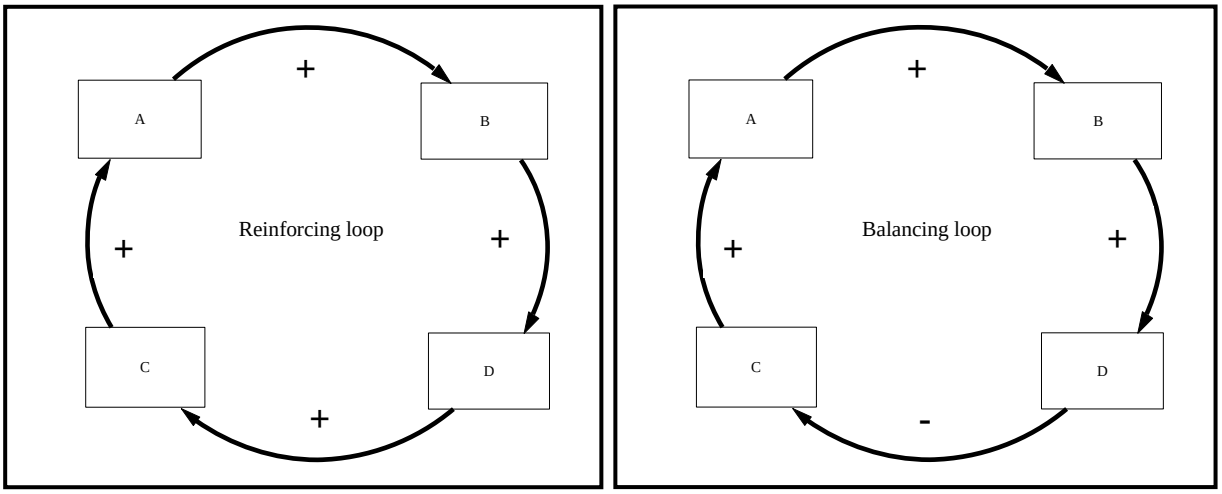
terrorist organization in the long run because there are an increasing number of paths aiding the terrorist structure.

Network stability

In the last part of the network analysis section, *network robustness* is the central issue. In this context, feedback cycles play a crucial role. Feedback loops are structural elements of networks that mostly determine these networks' stability. Feedback cycles are closed loops starting and ending at the same node. This structure implies that a change in an involved variable affects not only subsequent elements but also the changing variable itself.

Feedback loops are generally classified into two categories: *reinforcing* or positive feedback cycles and *balancing* or negative feedback cycles. Figure 7 illustrates the difference between these two different feedback systems.

Figure 7. Reinforcing and balancing feedback loops



Reinforcing feedback cycles are destabilizing factors in a system. Each variable involved is either growing (*motor*) or declining over time. In short, positive feedback loops boost or amplify whatever is occurring in the system. In contrast to reinforcing cycles, balancing feedback loops equilibrate the system. If variable A is stimulated positively, the impulse will

change polarity during the loop and have a negative impact on variable A. Therefore, negative feedback cycles are self-correcting and aid stability.[47]

Figure 8. Central reinforcing feedback loops

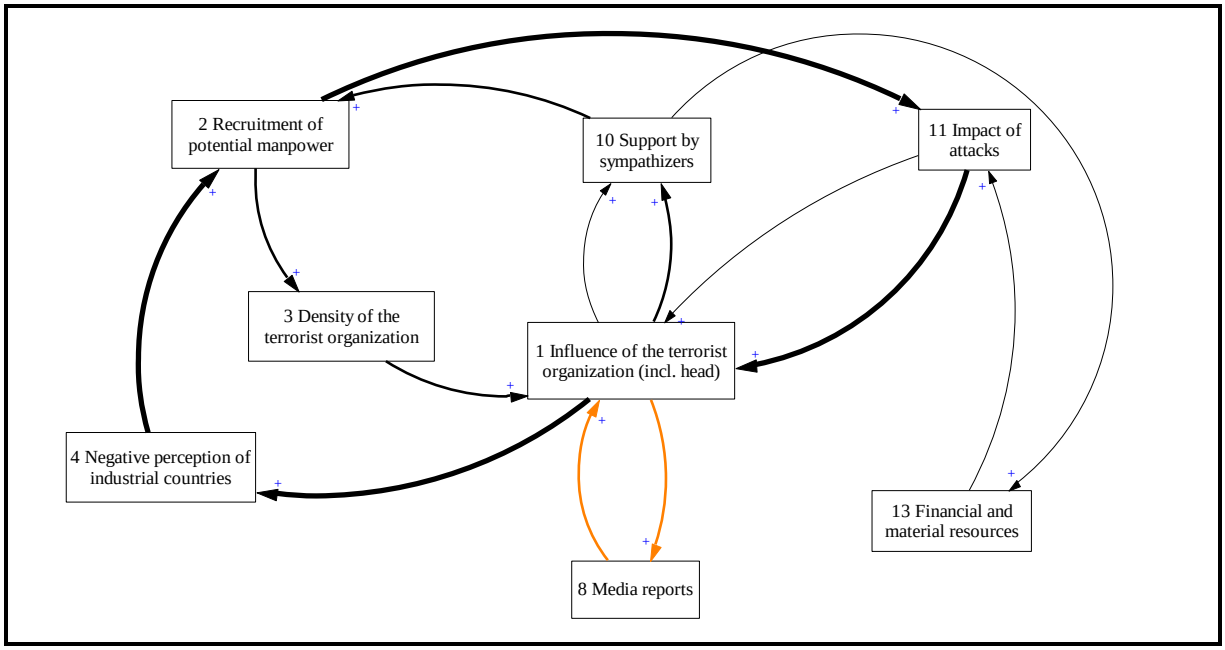


Figure 8 depicts the four primary positive feedback cycles that increase the *influence of the terrorist organization*. For better visualization, we added two redundant links between the variable pairs 1/10 and 1/11. There is one small cycle including *media reports* in addition to *influence of the terrorist organization*. Additionally there are three larger feedback loops, each containing four variables. It is important to note that three influencing factors (*recruitment of potential manpower*, *support by sympathizers* and *impact of attacks*) participate in two feedback cycles.

To better understand the structure of the terror network, we applied a search algorithm on feedback cycles.[48] The following issues are important in this context:

- How many different feedback loops appear in our terror model?
- What are the shares of reinforcing and balancing feedback loops?

- What are the consequences for network stability if single or multiple variables are removed?

The third point is of special interest for policy makers. It is critically important to know which variables or combination of variables must be addressed to break down terror networks. Table 5 summarizes the results of particular analysis.

Table 5: Policy on/off analysis

removed variable(s)	# feedbacks	# reinforcing (+)	# balancing (-)	min. path	max. path	# remaining feedbacks (in %)	ratio ingoing paths on 1
Intact network	2450	1824	626	2	13	100.00%	0.81
1	405	297	108	2	12	16.53%	-
2	296	232	64	2	12	12.08%	0.76
3	859	730	129	2	11	35.06%	0.68
4	937	707	230	2	12	38.24%	0.79
5	1911	1465	446	2	13	78.00%	0.69
6	1910	1430	480	2	13	77.96%	0.87
7	376	290	86	2	10	15.35%	0.73
8	1649	1179	470	2	13	67.31%	0.88
9	1560	1121	439	2	13	63.67%	0.85
10	1253	938	315	2	12	51.14%	0.85
11	192	128	64	2	11	7.84%	1.1
12	1798	1238	560	2	13	73.39%	0.9
13	694	545	149	2	12	28.33%	0.87
14	954	732	222	2	13	38.94%	0.64
15	568	434	134	2	12	23.18%	0.61
16	2124	1791	333	2	13	86.69%	0.68
8;10;13	267	199	68	2	11	10.90%	1
10;11;13	72	51	21	2	9	2.94%	1.08
4;10;11	49	35	14	2	9	2.00%	1.12
2;11;3	22	22	0	2	8	0.90%	1
2;10;11	18	17	1	2	7	0.73%	1.04
2;4;11	13	12	1	2	7	0.53%	1.05
2;11;13	11	10	1	2	6	0.45%	1.06
2;11;8	6	5	1	2	5	0.24%	2.05

The upper part of Table 5 depicts the implications on the network if a *single* variable is deleted. The consequences for the network if *several* elements are removed can be observed in the lower part.

Because the established terror network in Figure 2 is quite complex and the elements are highly interconnected, many feedback loops exist. In total, there are 2450 feedback cycles composed of roughly 75 % reinforcing feedback loops and 25 % balancing feedback loops. The length of cycles varies between 2 and 13 variables.

To effectively combat our terror network, we must break the central reinforcing feedback loops displayed in Figure 8. Variable 11 (*impact of attacks*), which is part of two positive feedback cycles, has the greatest effect on network stability. If this element is removed from the system, the total number of feedback loops will decrease by approximately 92 %. This finding is not at all surprising because each terrorist organization plans and executes attacks to cause the most severe physical and psychological damage. Therefore, it is of great importance for every country threatened by terrorism to protect potential targets in the best possible way: by protecting particular buildings and places that have great historic value and those that attract many people. Another key variable is the *recruitment of potential manpower*. This is the *fuel* in the terror network. Stopping recruitment would cause the total number of feedback loops to drop by roughly 88 %. Stopping the inflow of new manpower in a terrorist organization is a complex task and requires a large amount of time and resources as well as a deep understanding of the underlying causes that lead young men to join a terror network. Often it is a lack of prospects in poor and underdeveloped countries that provides a foundation for terrorism.

The best results can be achieved if variables 2, 11 and 8 (*recruitment of potential manpower*, *impact of attacks* and *media reports*) are switched off. Effectively targeting these variables completely crushes the network and leaves only six feedback loops remaining. *Media reports*

play a crucial role in the context of terrorism. Attacks that generate a large echo in the media help to strengthen the influence of the terrorist organization. Therefore, the press should strike the right balance between informing and over-informing about terror attacks.

The last column of Table 5 shows the ratio between total number of negative and positive paths incoming on variable 1 (*influence of the terrorist organization*). As long as this value lies below 1 there is a net positive effect on the *influence of the terrorist organization.* If we just remove one variable the only possibility to lift this number above 1 is by switching off variable 11 (*impact of attacks*). Tackling multiple variables leads to very promising results especially the combination of variables 2, 11 and 8.

CONCLUSION

The goal of this paper is to approach the dangerous and widespread phenomenon called terrorism from a virtual novel perspective. Terrorism is a complex problem; therefore, simple solutions focusing on only one aspect are destined to fail. We must capture terrorism in its entirety, and qualitative system dynamics offers tools to support this end. The key to success is the modeling process. We must construct a model that reflects the most relevant influencing factors and their interdependencies accurately to produce reliable outcomes.

Once a well-grounded model is available, different analyses from the field of system dynamics can be performed. First, it is important to characterize each relationship and answer the following questions:

- How strongly does one variable influence another?
- How long does it take for this effect to be measurable?

A portfolio in which time and effect are mirrored enables the deduction of the best intervention variables in the system. By definition, a steering variable has a dominant position

in the network (high active sum) and quickly distributes stimuli throughout the network (low produced delay).

In our model, we found three variables suitable for intervention:

- *Control of overreaction*
- *Right target of anti-terror measures*
- *Anti-terror support by moderate forces*

Next, we studied in detail the effects of two intervention variables on the *influence of the terrorist organization*. Because there is not only one connecting path between the intervention and the target variable, we applied a pathfinder algorithm to reveal all possible routes. One astonishing result is that both *right target of anti-terror measures* and *anti-terror support by moderate forces* show, in addition to a dominant negative effect, a small enhancing effect on the influence of the terrorist organization.

Finally, we tested the robustness of the network by removing single and multiple variables. To completely break down our terror model, we must approach the problem in three different areas:

- *Recruitment of potential manpower*
- *Impact of attacks*
- *Media reports*

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